QUENCHED AND TEMPERED STEEL WIRE WITH SUPERIOR COLD FORGING CHARACTERISTICS

Technical Field

The present invention relates to steel wires or steel rods, suitable for use in manufacturing various parts for machine structures, such as bolts and shafts, having relatively high strength. More specifically, the present invention is directed to a quenched and tempered steel wire with superior cold forging characteristics, characterized in that additional heat treatment, such as quenching and tempering, is not performed after a cold forging process by maintaining a new factor affecting the cold forging characteristics of the steel wire in a predetermined range.

Background Art

In general, parts for machines with relatively high tensile strength between 700 and 1300 Mpa, for example, hexagonal headed bolts, U-shaped bolts, ball studs, shafts, etc., are obtained by subjecting steel wires or steel rods (hereinafter, referred to as 'steel wire') to a cold forging process. Specifically, the parts are manufactured in such a way that steel wire is heated at about 700°C for more than ten hours, but less than twenty hours so as to spheroidize the metal structures thereof, and then subjected to cold forging and heat-treating. Thereafter, the steel wire is necessarily subjected to additional heat treatment, such as quenching and tempering, to enhance the strength and toughness even after cold forging. That is, it is necessary to perform a plurality of manufacturing procedures due to its complicated manufacturing process, as shown below:

(Conventional manufacturing process of parts for machines)

Steel wire or steel rod → spheroidizing for a long period → cold forging → heating at high temperatures (850°C or more) → quenching (water or oil) → tempering → product

Hence, the conventional process has the following problems, and should be improved in energy efficiency, productivity and working conditions.

(1) A spheroidizing annealing process of steel wire for a long period leads to high energy loss and low productivity.

(2) Since processed steel wire is additionally subjected to quenching and tempering to enhance the strength and toughness thereof in a manufacturing process, its manufacturing time is lengthened. In addition, working conditions deteriorate where the steel wire is subjected to heat treatment in a manufacturing place. Where the heat treatment is subcontracted to an outside manufacturer, costs for heat treatment and labor for managing delivery schedules are increased, thereby complicating overall process management.

(3) Attributed to the problems disclosed in above items (1) and (2), productivity is reduced in view of the heat treatment process. Therefore, there exists an urgent need to improve productivity

Accordingly, low productivity, high manufacturing costs, and inferior working conditions, resulting from the heat treatment before or after the cold forging process, should be effectively improved.

Disclosure of the Invention

Leading to the present invention, intensive and thorough research on efficient manufacturing process of quenched and tempered steel wire, carried out by the present inventors aiming to avoid the problems encountered in the related art, resulted in the finding that a quenching process and a tempering process, which have been conventionally performed after cold forging, are conducted before cold forging process, whereby a quenched and tempered steel wire is subjected to only cold forging to manufacture a desired product, without additional heat treatment including quenching and tempering.

Therefore, the object of the present invention is to provide a quenched and tempered steel wire with superior cold forging characteristics.

Brief Description of the Drawings

FIG. 1 is a graph illustrating a relationship between critical compressibility (H_{crit}) and percent spheroidization of carbides in a quenched and tempered test piece of the present invention;

FIG. 2 is a sectional view of carbide present in a structure of a quenched and tempered steel wire of the present invention;

FIGS. 3a and 3b are enlarged photographs of the structure of quenched and tempered steel wire, photographed by a transmission electron microscope, in which FIG. 3a shows the structure of a conventionally quenched and tempered steel wire and FIG. 3b shows the structure of a quenched and tempered steel wire according to the present invention;

FIGS. 4a and 4b are views illustrating the shape of a compression test piece, in which FIG. 4a is a perspective view to show an overall shape and FIG. 4b is a plan view to show a notched part; and

FIG. 5 is a front view illustrating a hexagonal headed flange bolt.

Best Mode for Carrying Out the Invention

Since a quenched and tempered steel wire has high strength, a desired product cannot be manufactured merely by subjecting such a steel wire to a cold forging process. Therefore, as a result of lots of studies to manufacture a variety of complicated machine structural parts from high strength steel wire by a cold forging process, the present inventors have found that superior cold forging characteristics can result when a quenched and tempered steel wire having tensile strength of 700-1300 Mpa has percent spheroidization of carbides deposited therein of 30% or more, as observed by a transmission electron microscope.

In other words, when the percent spheroidization of the deposited carbides in the steel wire quenched and tempered to have tensile strength of 700-

1300 Mpa before the cold forging process is not less than 30%, the steel wire has superior cold forging characteristics even though being high in strength. Thus, a cold forging process may be efficiently performed. Further, even after the cold forging process, the steel wire has relatively high strength required for various parts for machine structures. Accordingly, there is needed no additional heat treatment, such as quenching and tempering, to increase strength.

In the present invention, the quenched and tempered steel wire comprises a C-Si-Mn alloy, consisting essentially of 0.1-0.5 wt% of C, 1.0 wt% or less of Si, 0.2-2.5 wt% of Mn, with the balance being Fe and inevitable impurities. As necessary, the quenched and tempered steel wire further includes any one selected from among 0.05-2.0 wt% of Cr, 0.05-1.5 wt% of Mo, 0.0003-0.0050 wt% of B, or mixtures thereof.

Respective components constituting the quenched and tempered steel wire are defined as below in terms of properties and amounts.

C: 0.1-0.5 wt%

C is the most important element for use in increasing strength upon a quenching process. Generally speaking, if C is used in an amount less than 0.1 wt%, hardening effects by a quenching heat treatment cannot be expected. Meanwhile, if C is used in the amount exceeding 0.5 wt%, carbides are excessively deposited, thus reducing toughness and increasing resistance to deformation, resulting in decreasing a service life of manufactured tools as well as generating cracks upon a cold forging process.

Si: 1.0 wt% or less

Si is used to deoxidize the steel and to increase the strength by solid-solution characteristics. However, the addition of Si exceeding 1.0 wt% leads to the reduction in toughness, and deformation resistance is enhanced upon a cold forging process, thus generating cracks and shortening a service life of tools. This is because Si is solid-dissolved in the deposited carbides, and thus hinders carbon movements so as to prevent carbides from spheroidizing.

Mn: 0.2-2.5 wt%

Mn functions to enhance solid-solution characteristics. When C and Si are used in smaller amounts to avoid the enhancement of deformation resistance due to excessive addition of C and Si, Mn is used to supplement the strength of the steel. For this, Mn is used in the amount of at least 0.2 wt%, and does not exceed 2.5 wt% because excessive addition of Mn results in the increase in the toughness and deformation resistance.

Cr: 0.05-2.0 wt%

Cr is used to increase strength, quenchability and ductility. The addition of Cr less than 0.05 wt% results in the reduction in the properties as stated above. Also, when expensive Cr is used in the amount exceeding 2.0 wt%, economic benefits are negated. Thus, a lower limit of Cr is set to 0.05 wt%, and an upper limit of Cr is to 2.0 wt%.

Mo: 0.05-1.5 wt%

Mo has the same addition effects as Cr. That is, when Mo is used in the amount less than 0.05 wt%, the above properties become poor. On the other hand, the addition of Mo exceeding 1.5 wt% results in increasing the resistance to deformation. Hence, Mo should not exceed 1.5 wt%.

B: 0.0003-0.0050 wt%

B is used to increase quenchability. If the adding amount of B is less than 0.0003 wt%, there are no addition effects. Meanwhile, if the amount exceeds 0.0050 wt%, the quenchability is slightly decreased. Further, B reacts with N in the steel structure to produce BN, which functions to break grain boundaries. Thus, Ti with higher affinity to N is added in the amount of 0.01-0.05 wt%, so as to increase the addition effects of B. As well, Zr or Nb having the same function to Ti is preferably used.

P and S, as inevitable impurities, act to reduce a degree of deformation upon cold processing. Particularly, if these components are used in the amount exceeding 0.030 wt%, many cracks appear upon cold processing. Thus, it is favorable that the amount of P and S is in the range of 0.030 wt% or less.

As for the quenched and tempered steel wire, tensile strength after the

quenching and tempering treatment is limited in the range of 700-1300 Mpa. If tensile strength is less than 700 Mpa, the ductility increases. Thus, only when being processed in small quantities, a hot rolled wire material (structure: ferrite + pearlite) may be subjected to a cold forging process. Further, the steel wire having tensile strength of the above value is unsuitable for use in machine parts. On the other hand, at tensile strength exceeding 1300 Mpa, hardness of the wire material is high, thus reducing a service life of tools. In addition, it is difficult to make machine parts having a complicated shape.

Further, the reason why the percent spheroidization of carbides of the steel wire is defined to 30% or more to achieve superior cold forging characteristics, as observed by a transmission electron microscope, is described, later.

Referring to FIG. 1, 16mm across wire materials, including JIS G 4105 SCM420, JIS G 4051 S35C and JIS G 4106 SMn433, are drawn to have a diameter of 15.0 mm, and heated at AC3 point or higher and then cooled with water or oil. Each wire material is tempered under conditions of various heating temperatures and heating times and then observed by a transmission electron microscope. Behavior of critical compressibility (H_{crit}) according to the percent spheroidization of carbides of the wire material is shown in FIG. 1. Depending on shapes of carbides deposited from the martensite base, cold folding characteristics are varied. In particular, when the percent spheroidization is not less than 30%, critical compressibility as a parameter showing cold forging characteristics, is drastically increased to 40% or more. Thereby, excellent cold forging characteristics are exhibited.

This is because a distance between neighboring carbides is broadened as the shapes of the deposited carbides are close to a spheroidal form, the potential generated upon cold forging easily passes through therebetween, resulting in enhancing the ductility required for cold processing.

With the intention of maintaining the percent spheroidization of carbides at 30% or more, temperature and time conditions required for performing a

tempering process are further increased in the ranges capable of obtaining desired tensile strength, compared to general tempering conditions.

To determine the critical compressibility and the percent spheroidization of carbides of FIG. 1, a test piece is prepared and the values of the above factors are calculated, according to the following procedures.

As for the measurement of the percent spheroidization of carbides, the quenched and tempered steel wire is subjected to mechanical cutting, chemical polishing and electrolytic polishing at a cross section thereof, to prepare a thin film having a thickness of 0.1 mm or less. Thereafter, a 1/4 point of a circular diameter of the thin film is photographed 50,000-100,000 magnifications by means of a transmission electron microscope.

Then, on a photograph, a circle having 50-70 mm across is marked, in which respective carbides are measured for long directional length (L) and short directional length (S), as shown in FIG. 2. The short length is divided by the long length, which is shown as a percentage (%):

Percent Spheroidization = $S/L \times 100$ (%)

As such, the representative value is determined by measuring each percent spheroidization of the measurable carbides in the marked circle, which are then averaged, with the exception of the highest and the lowest values. The carbides at the lath boundaries or grain boundaries are excluded from the determination.

FIGS. 3a and 3b are enlarged photographs of the structure of the quenched and tempered steel wire photographed by a transmission electron microscope, in which FIG. 3a shows the structure of a steel wire quenched and tempered conventionally and FIG. 3b shows the structure of the steel wire quenched and tempered according to the present invention. In the case of the conventionally treated steel wire shown in FIG. 3a, needle-shaped carbides are present in a base structure and also a distance between adjacent carbides is very narrow. As shown in FIG. 3b, carbides in the steel wire according to the present

invention are present in a spheroidal form, and the distance between neighboring carbides is relatively broad.

In addition, the measurement of the critical compressibility is carried out by subjecting a compression test piece as shown in FIGS. 4a and 4b to a V-notch process and then a compressing process at various heights, whereby a bottom surface of the V-notched part is observed 10 magnifications by a magnifying glass. The critical compressibility (H_{crit}) when 1 mm long cracks appear is calculated according to the following equation:

$$H_{crit} = \frac{H_0 - H_1}{H_1} \times 100(\%)$$

wherein

H_0: an original height of a test piece (mm)

H_1: a height of a test piece when 1 mm cracks are generated on a bottom surface of V-notch (mm)

The V-notch compression test is used to evaluate whether cold forging characteristics are superior. The present inventors have practically performed cold forging processing for a plurality of steel wire test pieces having different values of critical compressibility. Thereby, it can be confirmed that cold forging characteristics are superior when the critical compressibility is 40% or more. Thus, the above value is regarded as a parameter showing cold forging characteristics.

In addition, the cold forging characteristics of the quenched and tempered steel are greatly affected by the percent spheroidization of carbides deposited after quenching and tempering. In particular, when the percent spheroidization of carbides is not less than 30%, the quenched and tempered steel wire with superior cold forging characteristics can be manufactured. From this, it appears that the percent spheroidization acts as an important factor required for manufacturing the steel wire having superior cold forging characteristics.

The present invention will be more clearly understood from the following

example.

To clarify the above results, seven kinds of 16 mm across hot rolled wire rods having chemical compositions shown in Table 1, below, were used and stretched to have a diameter of 15 mm.

TABLE 1
Chemical Compositions of Steel Wire (wt%)

Steel Wire Sample No.	C	Si	Mn	P	S	Cr	Mo	B	Fe
1	0.18	0.15	1.45	0.010	0.007	-	-	0.0020	bal.
2	0.20	0.25	0.75	0.013	0.008	1.01	-	-	bal.
3	0.23	0.27	0.82	0.009	0.007	0.95	0.23	-	bal.
4	0.32	0.96	0.75	0.010	0.009	-	-	-	bal.
5	0.34	0.24	0.92	0.011	0.010	-	-	-	bal.
6	0.35	0.43	1.75	0.012	0.007	-	-	-	bal.
7	0.37	0.28	0.73	0.009	0.007	1.11	1.19	-	bal.

Each of the seven kinds of stretched wire rods was heated to temperatures of AC3 transformation points or higher by the use of a high frequency induction heating device capable of performing the series of processes, and then cooled with water. Then, the high frequency induction heating was further performed while the heating temperature and time were adjusted in the range of 200°C to AC1 transformation points so that the tensile strength of the wire was in the range of 700-1300 Mpa, thereby manufacturing heat-treated steel wires as test pieces of examples and comparative examples shown in Table 2, below.

The cross sections of each of the heat-treated steel wires were subjected to mechanical cutting, chemical polishing, and electrolytic polishing, and thus cut and polished to thin films having a thickness of 0.1 mm. Then, in respective thin films, a 1/4 point of a circular diameter was photographed 100,000 magnifications by a transmission electron microscope at an acceleration voltage of 200 KV, whereby the shapes of carbides in respective test pieces were observed and each percent spheroidization thereof was calculated.

In addition, each test piece was subjected to tensile test to determine tensile strength (TS). A compression test piece as in FIGS. 4a and 4b was

subjected to a compression test, to determine the critical compressibility (H_{crit}). Further, a hexagonal headed flange bolt shown in FIG. 5 was subjected to cold processing, whereby whether any cracks appeared at the weakest portions, indicated by arrows, was examined. The results are shown in Table 2, below.

TABLE 2

Cold Forging Characteristics of Quenched and Tempered Steel Wire

		Tensile Strength (N/mm^2)	Spheroidization (%)	Critical Compres. (%)	Cracks in Bolts
Steel Wire Sample 1	Ex. 1	782	72.1	68.2	○
	Ex. 2	825	41.3	63.7	○
	Ex. 3	827	31.5	46.4	○
	C.Ex.1	836	29.3	38.2	×
Steel Wire Sample 2	Ex.4	838	60.8	67.5	○
	Ex.5	843	36.1	58.3	○
	Ex.6	952	32.6	48.7	○
	C.Ex.2	863	29.0	37.1	×
Steel Wire Sample 3	Ex.7	857	67.2	65.4	○
	Ex.8	952	48.9	62.5	○
	Ex.9	987	33.1	48.9	○
	C.Ex.3	1073	28.3	37.3	×
Steel Wire Sample 4	Ex.10	947	57.9	55.6	○
	Ex.11	961	32.4	42.3	○
	C.Ex.4	832	28.7	32.7	×
	C.Ex.5	1105	18.5	16.4	×
Steel Wire Sample 5	Ex.12	998	65.2	62.7	○
	Ex.13	807	44.8	57.3	○
	Ex.14	1015	31.9	42.3	○
	C.Ex.6	1120	28.5	32.5	×
Steel Wire Sample 6	Ex.15	1052	56.3	57.2	○
	Ex.16	972	43.2	54.1	○
	Ex.17	1093	32.8	42.1	○
	C.Ex.7	895	28.8	31.8	×
Steel Wire Sample 7	Ex.18	1095	53.0	51.6	○
	Ex.19	813	33.2	42.0	○
	C.Ex.8	1106	28.1	29.9	×
	C.Ex.9	987	15.0	13.7	×

Note: ○: appearance of no cracks,
×: appearance of cracks

From Table 2, it can be seen that the test pieces of the present invention

having the percent spheroidization of 30% or more represent the critical compressibility (H_{crit}) of 40% or more, regardless of kinds of steel. Further, since practically forged parts have no cracks, it will be apparent that the steel wire of the present invention exhibit superior cold forging characteristics.

The following Table 3 shows characteristics of steel wire stretched to 2-25% after the steel wire having compositions of Table 1 was subjected to heat treatment, such as quenching and tempering.

TABLE 3

Cold Forging Characteristics of Steel Wire Stretched After Quenching and Tempering

		Tensile Strength (N/mm^2)	Spheroidization (%)	Critical Compres. (%)	Stretch (%)	Cracks in Bolts
Steel Wire Sample 1	Ex. 20	897	63.8	64.6	25.0	O
	Ex. 21	915	43.3	62.8	10.7	O
	Ex. 22	872	30.9	44.7	5.1	O
	C.Ex.10	988	28.7	36.5	13.2	×
Steel Wire Sample 2	Ex.23	855	62.5	60.3	5.0	O
	Ex.24	913	33.0	53.7	13.2	O
	C.Ex.11	930	28.5	34.2	17.8	×
	C.Ex.12	1170	16.2	27.0	25.0	×
Steel Wire Sample 3	Ex.25	995	68.2	63.2	21.8	O
	Ex.26	887	42.5	59.6	15.0	O
	Ex.27	1132	32.6	45.1	17.2	O
	C.Ex.13	908	28.8	35.4	5.0	×
Steel Wire Sample 4	Ex.28	986	55.2	52.9	8.9	O
	Ex.29	870	40.8	47.1	5.2	O
	Ex.30	1035	32.1	42.1	16.3	O
	C.Ex.14	1073	29.1	31.3	24.8	×
Steel Wire Sample 5	Ex.31	1095	63.3	60.5	5.0	O
	Ex.32	968	40.1	55.2	16.2	O
	Ex.33	897	31.8	41.6	10.0	O
	C.Ex.15	1125	28.3	33.5	25.0	×
Steel Wire Sample 6	Ex.34	1075	59.1	54.2	10.3	O
	Ex.35	869	32.5	43.0	5.1	O
	C.Ex.16	978	28.9	25.2	17.2	×
	C.Ex.17	1183	19.3	11.8	25.0	×
Steel Wire Sample 7	Ex.36	893	51.2	48.8	8.9	O
	Ex.37	972	44.3	45.6	5.0	O
	Ex.38	1190	31.0	41.3	25.0	O
	C.Ex.18	1070	28.4	27.0	13.2	×

Note: O: appearance of no cracks,
×: appearance of cracks

As shown in Table 3, a stretching process after quenching and tempering has no influence on the microstructures of carbides of the quenched and tempered steel wire of the present invention, and thus superior cold forging characteristics are maintained at a predetermined level.

Industrial Applicability

As described above, the present invention provides a quenched and tempered steel wire having superior cold forging characteristics. Such steel wire is advantageous in that:

(1) in the manufacturing of steel wire, there is required no spheroidizing annealing process requiring a long period, and thus it is possible to manufacture quenched and tempered steel wire having cold forging characteristics equal or superior to those of speroidizing annealed steel wires, thus increasing productivity.

(2) in the manufacturing of machine parts, quenching and tempering processes are not additionally performed for the enhancement of strengths obtained after a forging process, thereby achieving energy saving and improvement of working conditions. Further, by performing only a forging process, it is possible to manufacture machine parts having strength and toughness equal or superior to those of conventional wires. Thus, management of product quality and process are simplified, resulting in improvement in productivity.

Although the preferred embodiments of the present invention have been disclosed for illustrative purposes, those skilled in the art will appreciate that various modifications, additions and substitutions are possible, without departing from the scope and spirit of the invention as disclosed in the accompanying claims.